On Establishing Common Requirements for Water Mist Systems in Protecting Ordinary Combustible Fires

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Outline

• Background
• Class A fire suppression requirements and controlling factors
• Droplet size’s impact on key fire suppression mechanisms
• The fire sprinkler case
• The water mist case
• Recommendations
Recent questions about Class A fire protection in the water mist fire protection community:

- **What is the required operational area for water mist systems?**
- **Can the requirements for fire sprinklers be applied to water mist systems?**
- **Can the same operational area requirements be applied to different water mist systems?**
Requirements:
• Flame extinction in the gas phase
• Reducing fuel pyrolysis sufficiently

Controlling factors for fire suppression:
1) Spray characteristics – impact on cooling, inerting fire environment, radiation attenuation, fire plume penetration capability
2) Fire Hazard
   • Building height and storage height
   • Ventilation condition
   • Fuel properties – flammability and water absorption propensity
   • Storage arrangement
   • Surface or deep-seated fire
   • Degree of obstruction between fire and spraying nozzles
Class A Fire Suppression by Water - 2

Two-tier Fire Suppression Test

Heat Release Rate

Time from Ignition

\[ \Delta Q = Q(t-t_0) \]

Number of Tiers

2
3
4

Fire Suppression Water Flux for \( \frac{\Delta Q_a}{\Delta Q_{ao}} = 0.67 \) in 240-s Water Application (mm/min)

Class 2 Commodity

Plastic Commodity

2  6.9  11.4
3  10.5  16.3
4  13.4  21.2

Tiers

Two-tier Fire Suppression Test

\( Q_{ao} \)

\( t \)

\( t_0 \)

Time from Ignition

\( \Delta Q_a = Q_a(t-t_0) \)
Droplet size impact -1

For the same amount of water in the space,

\[ N \sim \frac{1}{d^3} \quad , \quad N=\text{droplet number density} \]
\[ A_w \sim \frac{1}{d} \quad , \quad A_w=\text{total droplet surface area} \]

The vaporization rate per droplet:

\[ m_d = 2\pi d \left( \frac{k}{C_p} \right) g \ln \left(1 + \frac{Y_{d,\text{surface}} - Y_\infty}{1-Y_{d,\text{surface}}} \right) \]

The total vaporization rate \( = N m_d \sim \frac{1}{d^2} \Rightarrow \)

The smaller the droplet, the greater cooling and inerting

Thermal radiation transmission \( \sim \exp^{-k f_v / d} \), \( f_v = \text{water volume fraction} \)

\( \Rightarrow \) the smaller the droplet, the greater the attenuation.
Droplet size impact – 2

An example of the evolution of a single droplet injected into opposing air stream:

- A droplet at a starting temperature of 20 °C is discharged downward into a 100 °C dry air stream
- Air velocity: 5 m/s upward
- Starting droplet velocity: 50 m/s downward
Droplet size impact – 3

An Example of Water Spray Penetration Propensity:

Droplet diameter $\propto D^{2/3}P^{-1/3} \propto (D^2/\dot{Q}_w^{2/3})$

- $D =$ Nozzle orifice diameter
- $P =$ Nozzle operating pressure
- $\dot{Q}_w =$ Water discharge rate
- $Pe =$ Fraction of water flux reaching the fire plume base
For the protection of a fire hazard, approval standards, such as FM Approvals Class 2000 and Class 2008, require that sprinklers have to meet certain water spray distribution and penetration requirements. As a result, different sprinkler models in a system category tend to:

1) have the same or similar orifice diameters
2) operate at the same or comparable pressures
   ⇒ comparable discharge rates and droplet sizes
3) have the same or similar spray angles and nozzle spacings
   ⇒ comparable penetration capabilities

Installation standards, such as FM Global OS 8-9 and NFPA 13, can therefore impose the same water supply requirement and operational area for different sprinkler models in a system category.
The Case of Fire Sprinklers – 2

An example:

• The ESFR sprinklers have to meet certain spray penetration requirements in ADD (Actual Delivered Density) measurements.

• Comparable spray patterns, droplet sizes and discharge rates at the same operating pressures among different ESFR sprinklers.
The Case of Water Mist Systems – 1

• Current standards, such as FM Approvals Class 5560 and CEN TS 14972, do not impose water mist spray requirements for certification of protecting a fire hazard. The systems are certified as is by fire testing.

• For the same protection, the systems could be very different:
  - single-fluid or twin-fluid
  - Different gases used in twin-fluid systems, such as air, $N_2$, $CO_2$
  - single-orifice or multiple-orifice
  - wide range of operating pressures (up to 140 bar or higher)
  - wide range of spray angles
  - Wide range of droplet sizes (as long as smaller than 1000 μm for 99% of discharged rate per NFPA 750)
The Case of Water Mist Systems – 2

• For different systems, the different fire suppression mechanisms, such as gas-phase cooling, fuel cooling, oxygen displacement, fuel vapor dilution, radiation attenuation and others, may play at different levels of significance in the fire suppression process. ⇒ Affect the protection result

• For instance, a system conducive to droplet evaporation, which is expected to be better at gas-phase cooling, oxygen displacement, fuel vapor dilution and radiation attenuation, may need a larger operational area in an open environment, as compared to a system having a better capability in delivering water to the fire source to directly cool the burning combustibles.
Recommendations

To be able to impose the same operational area requirement for different water mist systems, and to achieve comparable fire protection result for a fire hazard in an open environment:

• Group water mist systems in a way similar to that for fire sprinkler systems.

• Include spray characteristics in the grouping process, i.e. droplet size, water flux, thrust force and their distributions.
Questions?